Developing the CRTM Active Sensor Module

Isaac Moradi[1,2,3], Benjamin Johnsson[4], Patrick Stegmann[4], Gerald Heymsfield[3], Ron Gelaro[2,3]

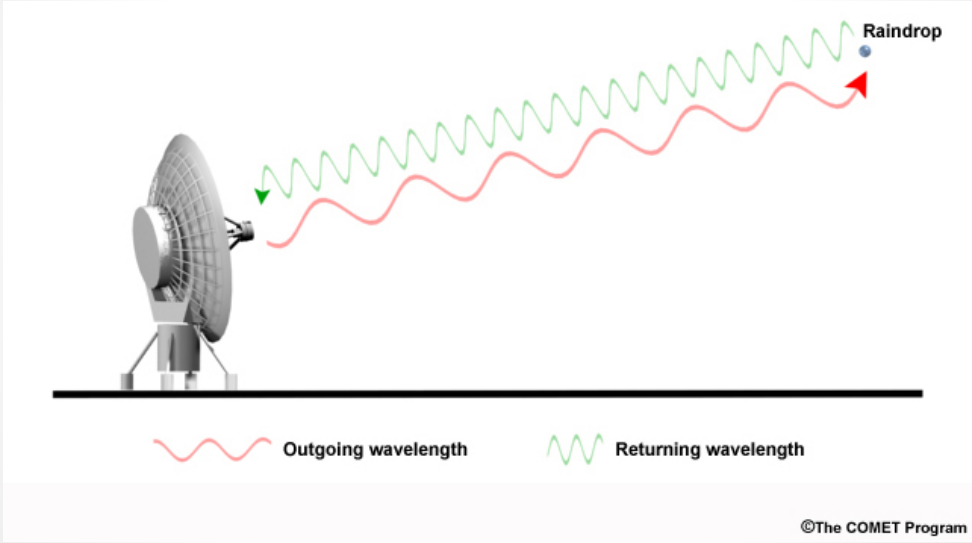
1. ESSIC, University of Maryland, College Park, MD
2. NASA Global Modeling and Assimilation Office, Greenbelt, MD
3. NASA Goddard Space Flight Center, Greenbelt, MD
4. Joint Center for Satellite Data Assimialtion, NCAR, Boulder, CO

January 10, 2023

This study was funded by the NASA MAP grant 80NSSC21K1361 entitled Assimilation of spaceborne radar measurements into NASA GEOS model.

Outline

How active instruments work?



The radar equation

The radar equation can be formalized as follows:

$$R = \frac{10^{18}\lambda^4}{\pi^5 \left|k_w\right|^2}\beta_b \qquad m^4 \;\; m^2 m^{-4} m^1 => mm^6 \; m^{-3} \tag{1}$$

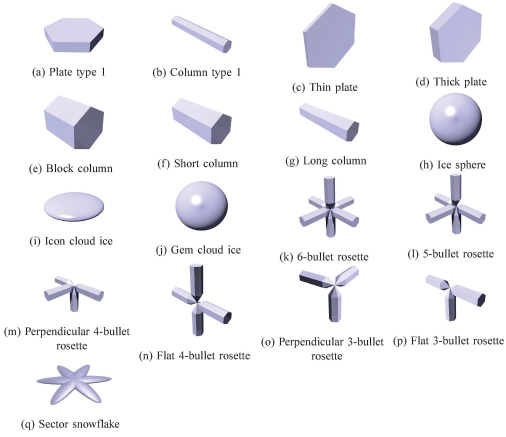
$$R_a = \frac{10^{18}\lambda^4}{\pi^5 \left|k_w\right|^2}\Gamma\beta_b \qquad m^4 \;\; m^2 m^{-4} m^1 => mm^6 \; m^{-3} \tag{2}$$

$$\beta_b = \int_0^\infty \sigma_b(D) n(D) \mathrm{d}D \qquad m^2 m^{-4} m^1 => m^{-1} \tag{3}$$

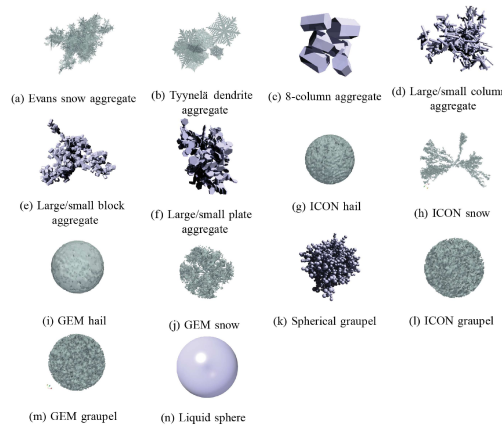
The unit for R (reflectivity) and R_a attenuated reflectivity are in $m^6 \; m^{-3}$ and 10^{18} is used to convert the unit to $mm^6 \; m^{-3}$. This is in turn converted to dBz or decibels by taking $R_e = 10log_{10}(R)$ or $R_{ea} = 10log_{10}(R_a)$. The dielectric factor (k_w) is calculated using the complex permittivity of the liquid water, $|k_w|^2 = 0.75$.
Transmittance (attenuation) depends on both scattering and absorption coefficients.

$$\Gamma(h) = \exp\left(-2\int_h^{h_{sat}} k_e(h)\psi_c(h)\mathrm{d}r\right) = \exp\left(-2\sum_{i=h}^{h_{sat}} \tau(i)\right)$$

ARTS DDA Database



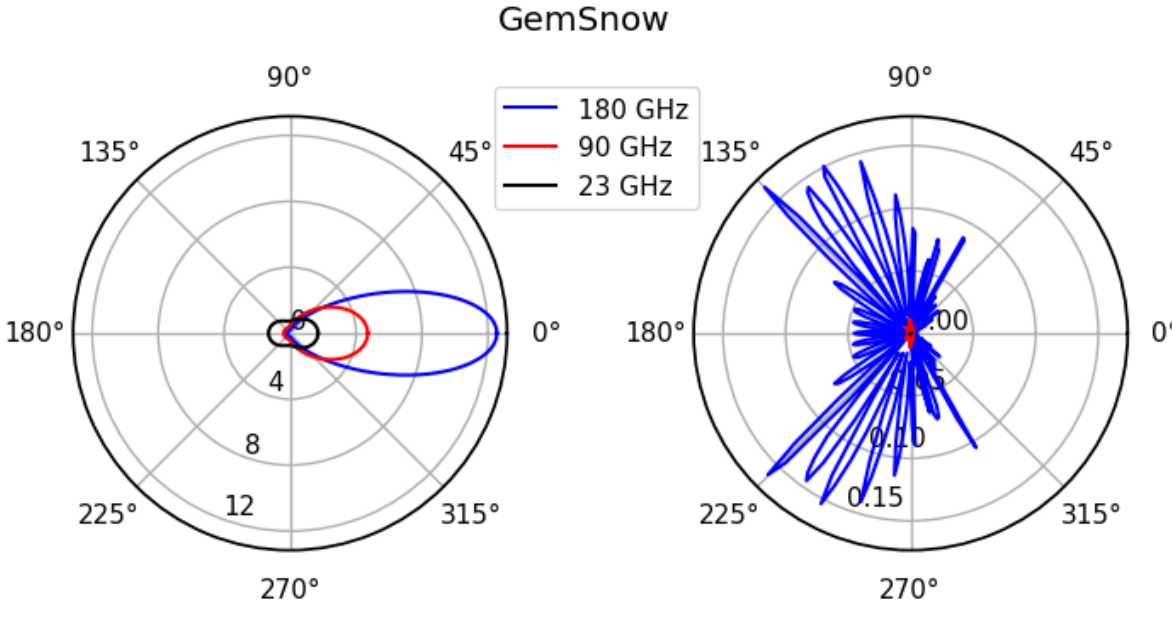
(a) Single crystal



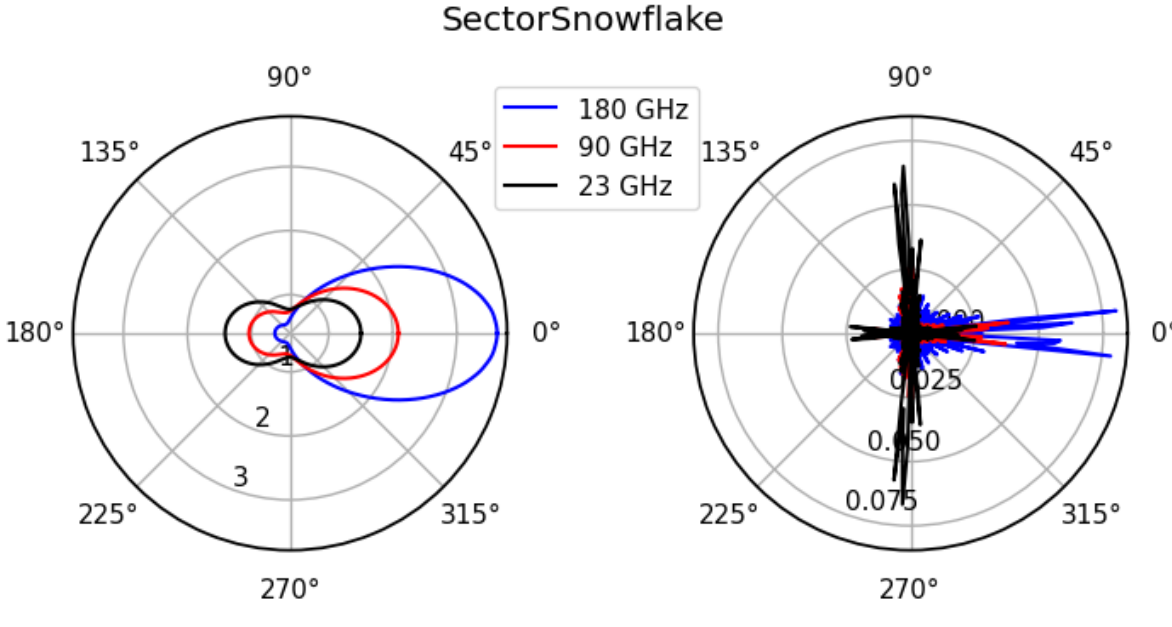
(b) Aggregates and liquid habits

Figure 4: Single crystal, aggregate, and liquid habits included in the database generated by *Eriksson et al.* (2018). Note that although habits "h" and "j" may look identical in the image, they have different aspect ratio.

Phase Function for Gem Snow

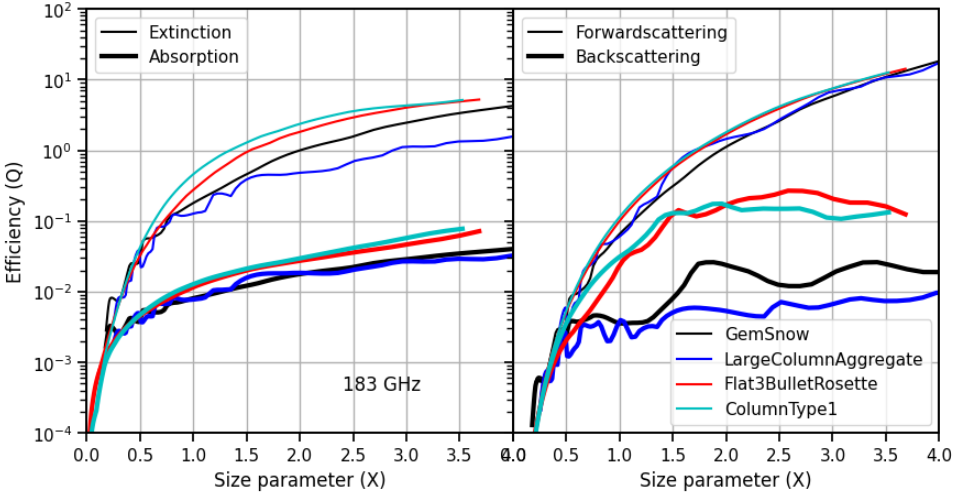


Phase Function for Sector Snowflake



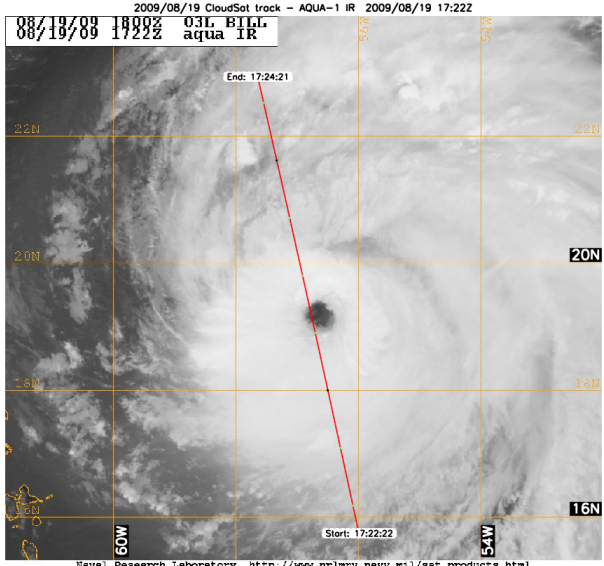
Backscattering Coefficients

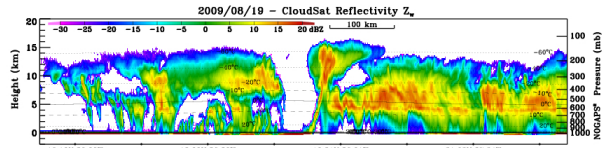
$$Q_\lambda = \frac{\sigma_\lambda}{\pi r^2} \qquad x = \frac{\pi D}{\lambda}$$



Extinction and backscattering efficiencies from the ARTS database for several different habits (Temp: 260 K)

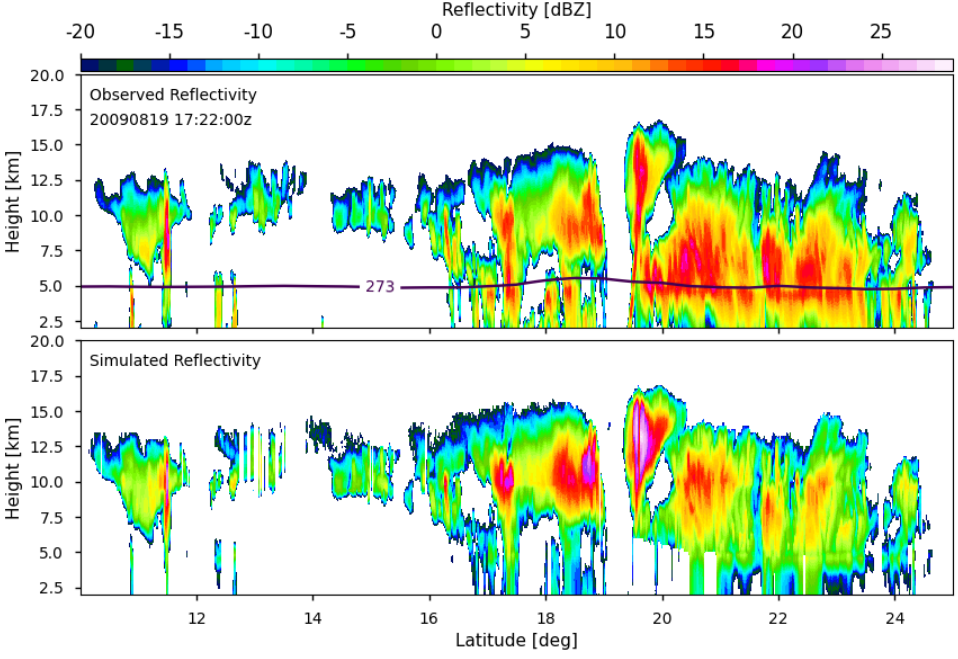
Hurricane Bill



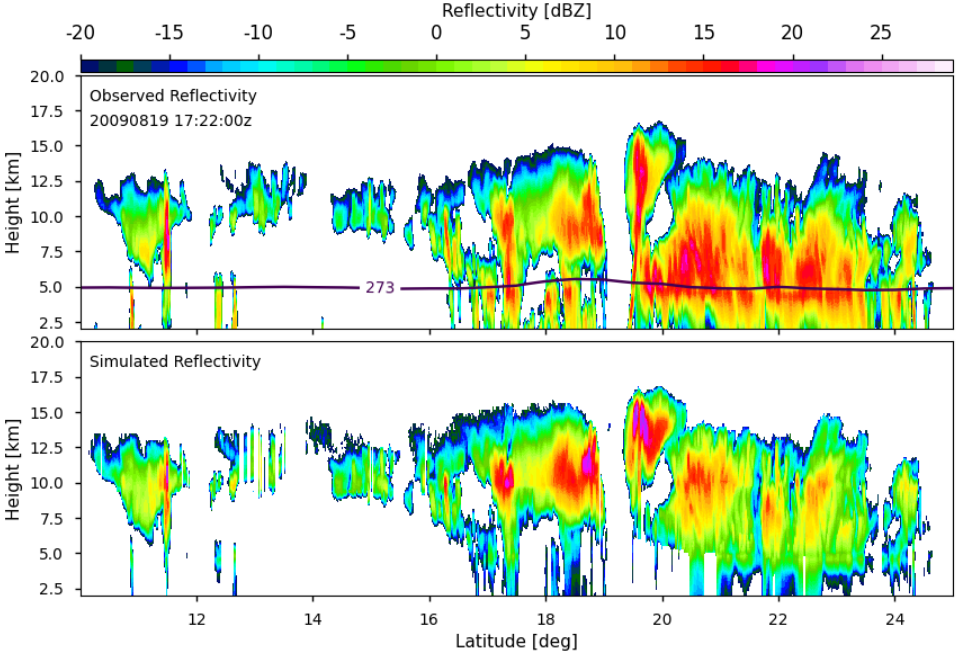


©CIRA/CloudSat

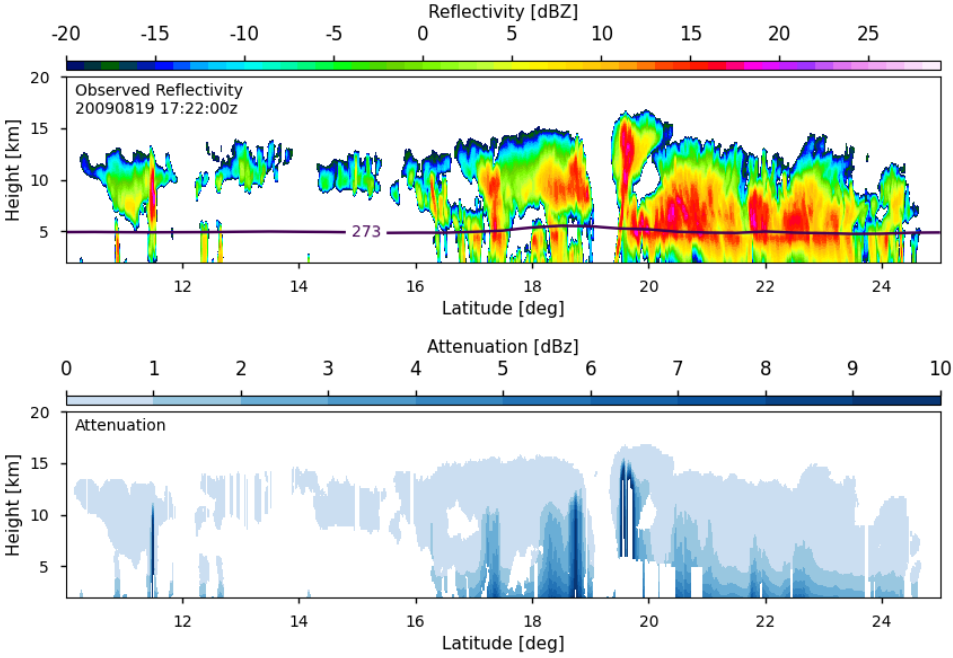
Hurricane Bill - Observed vs. simulated reflectivity



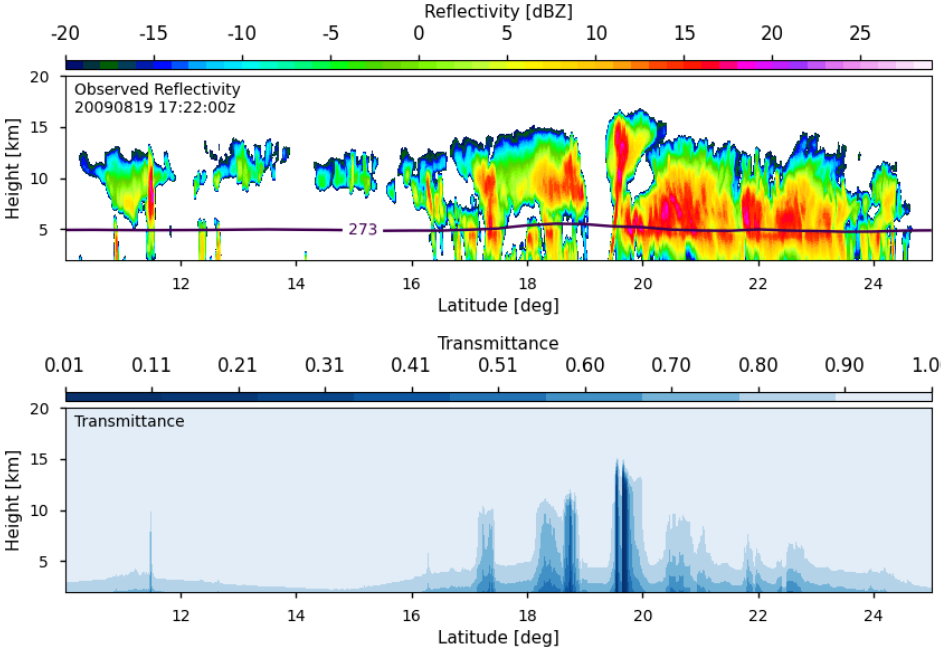
Hurricane Bill - Observed vs. attenuated simulated reflectivity



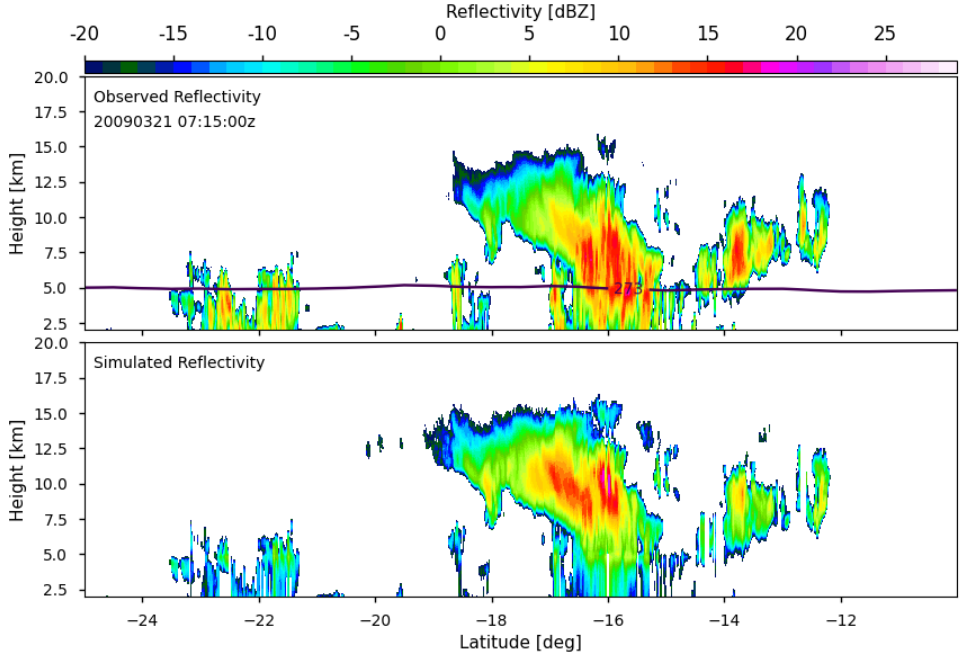
Hurricane Bill - Attenuation in dBz



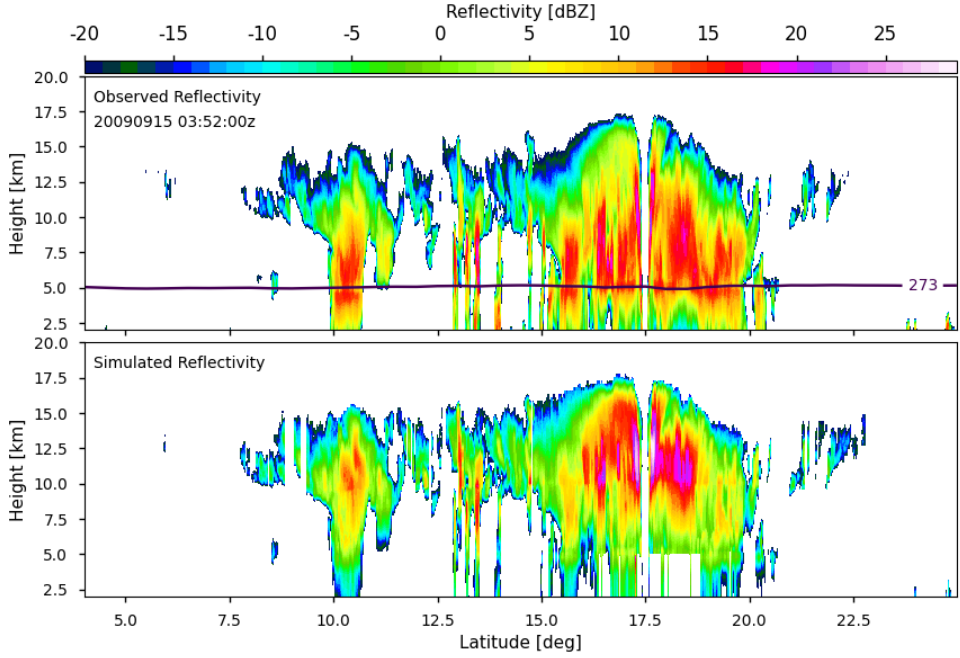
Hurricane Bill - Atmospheric Transmittance



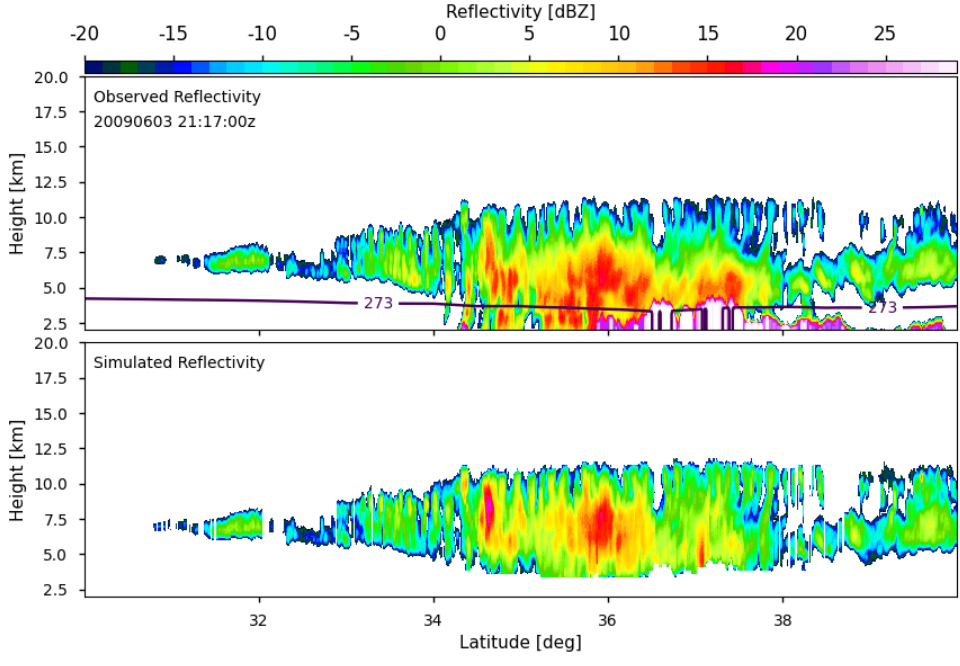
Tropical Cyclone Ilsa



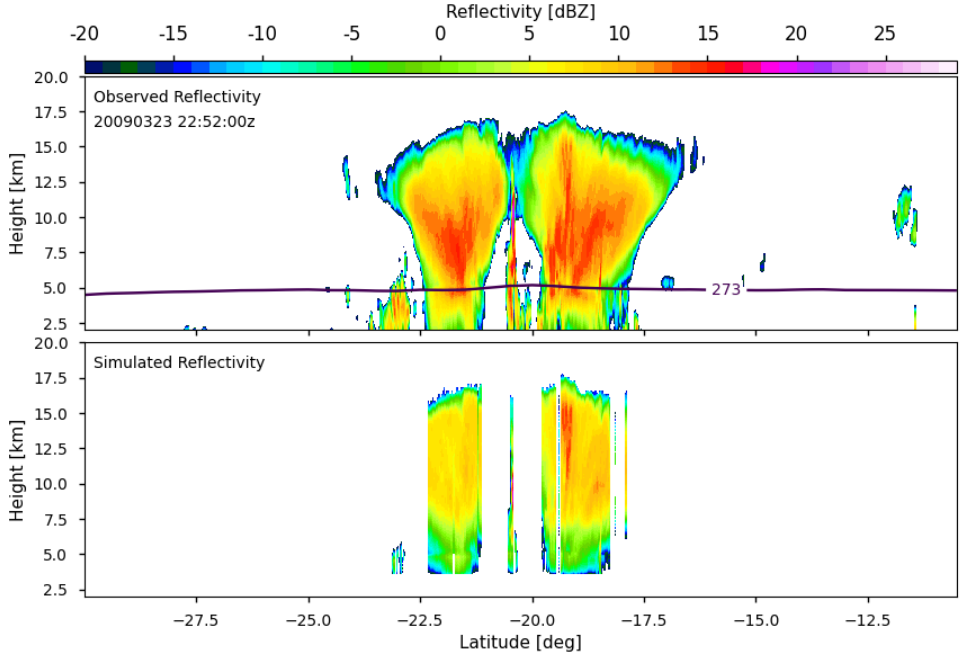
Typhoon Choi-Wen



Altocumulus undulatus over California



Tropical Cyclone Izilda



Tangent Linear and Adjoint of Active Radar Module

$$\begin{bmatrix} \partial\kappa_b \\ \partial\Gamma \\ \partial R \\ \partial R_a \\ \partial R_e \\ \partial R_{ae} \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ P_1 & 0 & 0 & 0 & 0 & 0 \\ P_1\Gamma & P_1\kappa_b & 0 & 0 & 0 & 0 \\ 0 & 0 & \frac{10}{R\ln 10} & 0 & 0 & 0 \\ 0 & 0 & 0 & \frac{10}{R_a\ln 10} & 0 & 0 \end{bmatrix} \begin{bmatrix} \partial\kappa_b \\ \partial\Gamma \\ \partial R \\ \partial R_a \\ \partial R_e \\ \partial R_{ae} \end{bmatrix}$$

$$\begin{bmatrix} \partial\kappa_b^* \\ \partial\Gamma^* \\ \partial R^* \\ \partial R_a^* \\ \partial R_e^* \\ \partial R_{ae}^* \end{bmatrix} = \begin{bmatrix} 1 & 0 & P_1 & P_1\Gamma & 0 & 0 \\ 0 & 1 & 0 & P_1\kappa_b & 0 & 0 \\ 0 & 0 & 0 & 0 & \frac{10}{R\ln 10} & 0 \\ 0 & 0 & 0 & 0 & 0 & \frac{10}{R_a\ln 10} \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} \partial\kappa_b^* \\ \partial\Gamma^* \\ \partial R^* \\ \partial R_a^* \\ \partial R_e^* \\ \partial R_{ae}^* \end{bmatrix}$$

Conclusions

- CRTM radar simulator as well as its adjoint and tangent linear are implemented and tested
- The radar module takes advantage of different CRTM atmospheric absorption and cloud scattering modules
- The radar simulator uses the backscattering coefficients included in the new DDA lookup tables
- The radar module can be used for the assimilation of observations from instruments such as CloudSat CPR, GPM DPR, and EarthCare CPR.
- Work is in progress to evaluate the active module especially within the JEDI DA system


Thank you for
your attention!